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Abstracts of american reports on reinforced concrete column investigations, 1930

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ABSTRACTS OF AMERICAN REPORTS

ON REINFORCED CONCRETE COLUMN INVESTIGATIONS

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9/15

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DISCUSSION OF NOTE ON THE COEFFICIENT OF ELASTICITY
OF CONCRETE AND MORTAR BEAMS DURING FLEXURE

by Gaetano Lanza

In Transactions of the American Society of Civil Engineers
Vol. 50, June, 1903, page 483

Twenty-eight columns were included in this report. Fourteen were 8 in. square, of which four were 6 ft. long, four were 12 ft. long, and six were 17 ft. long. Seven columns were 10 in. square, of which two were 6 ft. long, four were 12 ft. long, and one was 17 ft. long. Seven plain concrete columns were 8 in. square and 5 ft. long. The concrete mix was 1:3:4 by volume. The water content varied from 6 to 7-1/2% by weight. Some of the columns were built with one reinforcing rod placed at the center of the sections, and others with four rods placed respectively at the middle points of the four half diagonals of the section. The rods in the 8-in. square columns ended 1/2 in. from each end of the columns, while the rods in the 10-in. square columns ended flush with the ends of the column. The formula used for computing the breaking load was:

$$P = f(A' + rA'')$$

where f = strength of concrete

A' and A'' = areas of concrete and steel respectively, and

$r = n$ = modulus ratio

The strength results generally gave higher values than those computed. The age at test varied from 28 to 45 days.

RESULTS OF COMPARATIVE TESTS OF
PLAIN AND REINFORCED CONCRETE COLUMNS

by E. J. McCaustland

In Engineering News, Vol. 43, 1905, page 614

The tests were carried out at Cornell University, and included 13 plain and reinforced concrete columns. Two kinds of lateral reinforcement were used, ties and spirals. The columns were 10 in. in diameter and 40 in. long. The concrete mix was 1:3:5. Three of the columns were of mortar of 1:3 mix. The hoops had a cross-section of $1/8$ by 2 in. and were spaced 5 in. on centers in three of the columns, and 10 in. in three others. The outside diameter of the hoops corresponded to that of the columns. The columns having lateral but no longitudinal reinforcement should have an average maximum load of 216,800 lb. computed by Considère's formula. Columns with lateral and longitudinal reinforcement failed at 157,000 lb. against a computed value of 219,800 lb. The latter, however, had the ties spaced 10 in. on centers. The low value has been attributed to the fact that the rods were not entirely embedded in the concrete, but were free to buckle away from the column between hoops, and hence were probably never stressed to the elastic limit. ✓

RESULTS OF PLAIN AND REINFORCED CONCRETE COLUMN TESTS

AT WATERTOWN ARSENAL

by J. E. Howard

In Engineering News, Vol. 46, 1906, page 20

The number of column tests included in the report was 99, (total of tests made, 126). The columns were generally 8 ft. long and from 10 to 12 in. in diameter. The concrete mix varied from neat cement to a very lean concrete. The reinforcement included several percentages of longitudinal and lateral reinforcement. The percentages of longitudinal reinforcement were 2.86 and 4.63. The results showed that longitudinal as well as lateral reinforcement increased the strength of the column appreciably, and was larger for higher percentages of reinforcement than for lower. It was found that the longitudinally reinforced columns deformed slightly more than the plain columns of same concrete mix. This behavior is ascribed to the possible effect of the longitudinal steel in preventing the concrete to settle as well as in plain columns. The columns with lateral reinforcement (ties) showed a much larger deformity than did plain columns. It was found that the modulus of elasticity changed considerably with the increase in the load, especially for lean mixes and it is pointed out that for this reason the proportion of the load carried by steel in combination with concrete is subject to great fluctuations. The

Watertown Arsenal
by J. E. Howard

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longitudinal reinforcement is recommended to have an elastic limit of not less than 50,000 lb. per sq.in. because the ultimate deformations correspond to at least this value.

Columns were also tested for long continued load, but the results are not given.

TESTS OF CONCRETE AND REINFORCED CONCRETE COLUMNS

SERIES OF 1906

by A. N. Talbot

In Bulletin No.10, University of Illinois

Engineering Experiment Station (February, 1907)

The tests reported include 18 plain and longitudinally reinforced columns. The reinforcement consisted of longitudinal rods and some columns had ties around the longitudinal rods in order to hold them in place. The sand used was Attica river sand and the coarse aggregate consisted of crushed, nearly pure limestone from Kankakee. The coarse aggregate passed a 1-in. screen and retained on a 1/4-in. screen. The concrete mix was 1:2:3-3/4 by loose volume for all the columns.

The reinforcement consisted of plain round mild steel bars of an average yield point of 39,800 lb. per sq.in., and ultimate strength of 59,200 lb. per sq.in. Rods of 3/4-in. diameter were used in the 12-in. square columns, and the ties were 1/4-in. round rods.

Two specimens were made of a kind. The columns were 9 and 12 in. square and 6, 9, and 12 ft. long. The concrete control specimens were 12-in. cubes and 8 by 16-in. cylinders. Three different reinforcements were used, (1) no reinforcement, (2) vertical rods in the corners only, (3) vertical rods in the corners tied together at every 12-in. height by 1/4-in. rods.

The vertical rods were made 1 in. shorter than the columns with the intention of having 1/2 in. of concrete over the rods at each end. In some cases, however, the rods settled down to the bottom.

All specimens were capped with Plaster of Paris before the testing. The longitudinal deformations were obtained by means of extensometers attached to the columns. In six columns the load was increased progressively until failure, in ten the load was released at 1 to 2 thirds of the ultimate, and then reapplied. The load was released twice on one column, and one broke accidentally when being placed in the machine. The percentages of reinforcements were 1.2 and 1.5 for the 9 and 12-in. columns respectively, and the age at test varied from 59 to 71 days.

Most of the columns failed in the top or bottom third of the height, only three failed near the center. Ten failed near the top and four near the bottom. In estimating the load carried by the steel and that carried by the concrete Talbot subtracted from the total load the amount found for the steel by multiplying the measured unit deformation with the modulus of elasticity for steel. This difference had to be carried by the concrete.

The strain-stress relation for concrete is given as a typical parabolic curve with the vertex at the ultimate strength of the concrete. The average value for the abscissa of the vertex of the parabola was found to be about 0.00134. The final

deformation was lower for the reinforced columns than for the plain ones.

The average ultimate load for the plain columns was 1553 lb. per sq.in., varying from 1079 to 2004,. The average variation from the average was 18% which was not considered large. The average strength of the 12-in. cubes was 2205 lb. per sq.in., and of the 8 by 16-in. cylinders, 1490 lb. per sq.in. Talbot stated that two things are noticeable in the results. (1) That the maximum stresses taken by the concrete in reinforced columns are less than for the plain concrete columns, and (2) that the range of results is greater. He also stated that it would seem that in general the position of the ends of the reinforcing rods has not affected the results in any marked manner, and there is no apparent reason for giving greater or less weight to the strength of any column, even though he recognized the danger of slipping of the ends of the bars.

The average concrete strength in the reinforced columns based on the given method of computation was 1243 lb. per sq.in., or omitting column 10, 1290 lb. per sq.in., with an average variation of 16%. With no allowance for steel, the reinforced concrete columns gave an average of 1746 lb. per sq.in. gross area.

The concrete strength in reinforced columns was 15% less than that of the plain columns.

The ties did not increase the strength or change the condition of failure.

A discussion is then given of Tests on Concrete Columns at Watertown Arsenal reported in Tests of Metals for 1904. These columns were of 1:2:4 mix by volume. The bars were placed 1-7/8 in. from the surface, and where more than four rods were used, the remaining rods were placed symmetrically in the interior. A variety of forms of reinforcement was used. The rods were cut to exact length and always had a direct bearing upon the bearing plates of the testing machine. The loads were released several times, generally ten or more, and the age at test was about 3-1/2 months.

The parabolic stress-strain relation seemed to hold also for these columns. The number of columns included ~~was~~ 7, of which one ~~was~~ plain concrete.

"A study of the results shows that there is no marked characteristic difference in either stiffness or strength for columns made with any special form of reinforcing bars or with any given amount of reinforcement. For leaner concrete, and hence greater porosity, the difference in the elastic limits of the bars may be expected to have an effect upon the results."

TESTS OF CONCRETE AND REINFORCED CONCRETE COLUMNS

SERIES OF 1907

by

Arthur N. Talbot

Bulletin No. 20, University of Illinois
Engineering Experiment Station (1907)

Twenty-one plain columns and 30 laterally reinforced columns were included in the tests reported. Generally the columns were 12 in. in diameter and 10 ft. long, but a few columns were included in which the ratio of length to diameter ranged from 6 to 13. Eighteen of the reinforced columns had bands as lateral reinforcement and 12 had spirals. Control cylinders of the concrete consisted of 12-in. cubes, 6-in. cubes, and 8 by 16-in. cylinders. The mixes ranged from a 1:1.5:3 to a 1:4:8, the largest number of columns being of a 1:2:4 mix.

The reinforced columns had a 1/16 to 1/4-in. covering of the reinforcement. The columns remained in the molds for 10 days. After removal from the molds, the columns were sprinkled twice a day until they were tested.

Longitudinal and lateral deformation observations were made.

The top of the column was capped with a plaster of Paris cushion, and both bottom and top capping plates remained on the column during testing.

Tests of plain columns and their control specimens showed that the cubes were generally stronger than the columns, and that the cylinders and columns were of nearly equal strength. The plain columns generally failed at the mid-section. Two types of failure occurred, one termed diagonal shear, and the other called simple compression. All columns having rich concrete mixes showed diagonal shear failure, and those having lean mixes showed simple compression failure. The strength of the plain columns increased with an increase in the richness of the mix. It was found that the strengths increased proportionally to the increase of the ratio by weight of cement to total aggregate. It is pointed out that the increase in strength is not proportional to the increase in cost so that the richer mixes would be the more economical for a given strength of columns. The variation in strength of the concrete was large. For the 1:2:4 concrete tested at 60 days, the individual values ranged from 27% above to 35% below the average strength. The average variation was 12%.

The modulus of elasticity given is the initial modulus, and it was found that the modulus at an age of one-half year was about the same as that for 60 days.

The value found for Poisson's ratio for a 1:2:4 mix at 60 days varied from about $1/10$ to $1/6$ and near the ultimate load the value probably reached $1/4$.

The total amount of shortening at maximum load for lateral reinforced columns was much larger than for plain columns. The maximum strain for lateral reinforced columns varied from 0.006 to 0.015, or 6 to 20 times the maximum strain of plain columns. The longitudinal stress-strain curve of laterally reinforced columns was nearly of the same shape as that for plain columns up to the point of failure of the plain columns. Beyond this point the strain increased very rapidly with the increase in stress. The initial modulus of elasticity was found to be less for laterally reinforced columns than for plain columns of the same concrete mix.

The columns reinforced with bands showed an increase in strength due to the reinforcement approximately equal to the yield-point stress of the steel, times the area of the steel regardless of the strength of the concrete. The spirally reinforced columns seemed to increase in strength slightly more than the yield-point strength of the spiral, and little difference was found between the strength of high carbon and mild steel spiral. The strength formula given for lateral reinforced columns is:

$C = C' + pC''$, where C = maximum strength of column, C' = maximum strength of plain concrete column, C'' = coefficient for the lateral reinforcement, and p = percent of lateral reinforcement. For columns reinforced with band, the values given are:

$C = 1600 + 65,000p$ and for columns with spiral reinforcement:

$C = 1600 + 100,000p$

TESTS OF REINFORCED CONCRETE COLUMNS

at

Minneapolis, Minnesota

by

J. G. Houghton and W. P. Cowles

In Engineering News, Vol. 60, 1908, page 608

The tests included 17 reinforced and 2 plain concrete columns. The columns were 9 in. square and the length was 9 ft. for the reinforced, and 5 ft. for the plain columns. The lateral reinforcement consisted of ties. The longitudinal reinforcement varied from 0 to 2.43%. The concrete mix was 1:2:3.5 and the age at test varied from 52 to 158 days. The test results were very erratic so that no clear-cut conclusion could be drawn. There was no recognizable relation between the ultimate strength and the type or amount of reinforcement. The reinforced columns averaged about 25% stronger than the plain columns, though five of the 17 failed at lower loads than the plain columns.

REINFORCED CONCRETE COLUMNS

by

P. Gillespie and W. G. Swan

Published in The Canadian Engineer

May 1, 1908 (Vol. 15, No.18)

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Experiments were carried out on seven columns in the testing laboratory of the Department of Engineering of Toronto University. The columns had a cross-section of 3-1/2 by 5 in. and varied in length from 20 to 84 in. Five of the columns had 2.5% longitudinal reinforcement. The lateral reinforcement consisted of 3/16-in. steel hoops spaced 3.5 in. on center for two of the columns, while the other three had 3/16-in. spirals with 3.5^{in.}% pitch. Neat cement cappings placed the day before the tests, gave satisfactory results. Deformation measurements were taken by means of electric contact devices which gave readings to 0.0001 in. The strain-stress curve deviated from a straight line almost from the start. In computing the stress in steel and concrete, the assumption of steel and concrete deforming together was adopted. The steel had an elastic limit of 42,800 lb. per sq.in., and an ultimate strength of 66,400 lb. per sq.in. The ultimate strength of the plain concrete columns was 1643 lb. per sq.in.

The authors show that the strength of the columns was determined by the formula:

$$C' = C. (1 + (n-1).p)$$

where C' is the strength based on total cross section,

C is the strength of the concrete,

n is the ratio $\frac{E_s}{E_c}$ for the stress C ,

and p is the ratio of longitudinal reinforcement. The modulus of elasticity of concrete at the elastic limit of the steel was found to be 1,000,000 so that n was 30 at time of failure. The computed maximum stress amounted to 2415 lb. per sq.in., while the tests gave an average of 2280 lb. per sq.in., which is considered a very good check. It is pointed out that the hoops seem to have no effect upon the ultimate strength of the columns. Closer spacing of the hoops or smaller pitch of the spirals would probably give different results. The results of the tests were very uniform.

TESTS ON PLAIN AND REINFORCED CONCRETE COLUMNS

by M. O. Withey

Bulletin of the University of Wisconsin, No.300 (1909)

This series of tests included 20 columns 10 ft. in length. Five different types were used; (1) plain concrete columns, (2) columns reinforced with latticed angle structural steel columns, (3) columns reinforced with high carbon steel wire spirals, (4) columns reinforced with spirals and longitudinal mild steel rods, and (5) columns reinforced with longitudinal mild steel rods. All reinforced columns had a protective shell of one or two inches thickness outside the steel. The concrete was of a 1:2:4 mix by volume, and the mixing water varied from 9.5 to 10% of the weight of the dry materials. The variation in water content was found to be due mostly to the variation in moisture in the sand. Two or three 6 by 8-in. control cylinders were made with each column. All columns of a certain series were made on the same day. The longitudinal rods were milled to a uniform length. The columns were capped with 1-1 mortar and the thickness of the caps over the ends of the rods or angles of reinforcement was never more than $1/32$ in. The columns remained in the molds six days and from then on they were wetted twice

a day for one week, after which they were cured in the air of the laboratory until tested at the age of about two months. A blotting paper was inserted between each end of the column and the bearing plate before the testing. Longitudinal deformation and lateral deflection were observed. An attempt to measure lateral deformation was also made but given up. The modulus of elasticity of the control cylinders was determined.

The modulus of elasticity of the control cylinders at one-third ultimate strength averaged 3,000,000 lb. per sq.in. The average ultimate strength was 2275 lb. per sq.in., and the maximum variation from the average was 16%. The stress-strain curve for the cylinders followed very nearly a parabola having its vertex at the ultimate strength.

The plain columns gave a strength equal to 91% of the ultimate strength of the control cylinders. The modulus of elasticity for the plain columns was considerably larger than for the cylinders and for the longitudinal reinforced columns.

The columns having structural steel shapes as reinforcement were considerably tougher than the plain columns. The protective shell started to crack and partly spall off shortly after the elastic limit of the reinforcement had been reached or the ultimate deformation of plain concrete exceeded. The ultimate strength figured on gross areas of these columns,

was no larger than of the plain columns. Columns with the protective shell chipped off before the testing showed approximately the same strength as the core of the columns with protective shell. Tests on the reinforcement alone and of plain columns alone, indicated that the maximum load carried by the core of the reinforced columns was nearly equal to the sum of the loads carried by the reinforcement and by the plain column.

The columns having spiral reinforcement showed high strengths as well as toughness. The stress-strain curves for these columns were much the same as for the plain columns up to a certain stress. Beyond this stress the strain increased very much with a small increase in stress, and the curve became practically a straight line. The protective shell cracked and fell off before the ultimate load was reached. The increase in strength due to 1% spiral was found to correspond to 98,000 lb. per sq.in. for spiral of yield-point stress of 97,700 lb. per sq.in.

The columns reinforced both with longitudinal and spiral reinforcement showed a considerably higher ultimate strength than did the plain columns and the columns with spirals only. The protective shell started to crack after the steel had been stressed beyond its elastic limit and the strength of the shell was entirely destroyed before the

maximum load was reached. The average increase in strength attributed to one per cent longitudinal reinforcement was 204 lb. per sq.in. of core area or 20,400 lb. per sq.in. of steel. The yield-point stress of the longitudinal reinforcement was 41,570 so that an effectiveness of about 50% was obtained.

The columns having longitudinal, but no spiral reinforcement failed suddenly with the steel buckling out between the lateral ties. The increase in strength attributed to one per cent longitudinal reinforcement was found to be about 37% of the yield-point stress of the steel.

In the summary it is pointed out that the columns were exceptionally uniform in strength.

REINFORCED CONCRETE COLUMNS

by Peter Gillespie

in The Canadian Engineer, March 25, 1910, Vol.18, No.12

The tests reported in this article included a total of 25 columns. The columns were 6 in. in diameter and 21 in. long. The longitudinal reinforcement varied from 0 to 4.42% and the lateral from 0 to 5.7%. The lateral reinforcement consisted of hoops welded from steel flats and were of two thicknesses, 0.05 and 0.12 in.

One group of columns had no longitudinal steel except the three strips of thin iron spacers. Certain of the hoops were left exposed so that deformations could be measured by means of mirror extensometers. Longitudinal deformations were measured by means of an compressometer of a 50-in. gage length. The results showed that the steel stress varied with the compressive stress in the concrete, and indicated that the concrete within the hoops under high compression stresses, had reached a state of partial plasticity. After releasing the heavy loads, the extensometer on the hoops did not completely recover, indicating that the flow of the concrete had left the steel in a state of residual tension since usually the steel had not even approached the elastic limit. The following relation between the compressive stress in the concrete and the

accompanying stress in the encircling bands was given;

$$\frac{f_s}{f_c} = \frac{9}{4 + \frac{9}{2} \cdot p} \quad \text{where}$$

f_s is stress in steel,

f_c is stress in concrete,

p is per cent of steel bands,

9 is the stiffness ratio and

$1/4$ is Poisson's ratio.

This equation shows that the effect of the percent of steel on the $\frac{f_s}{f_c}$ ratio is rather small. The test results check this

formula fairly well and indicate that the stress in the hoops for the kind of material used is about twice the compressive stress in the concrete. It is stated that from these and other tests, it would be fair to allow 1000 lb. per sq.in. gross strength per per-cent of hooping reinforcement used. Tests on columns having longitudinal as well as hooping reinforcement, indicate higher strength than without hoops.

A comparison of cost of rich and lean concrete columns designed for a given strength, is given and shows a great advantage of the rich mix over the lean one. It was found more economical to increase the richness of the mix than to increase the amount of reinforcement, in order to obtain a given strength. A comparison with steel columns also showed that concrete was much cheaper than steel.

The experimental work was carried out at the Testing Laboratory of the McGill University in Montreal and in the Laboratory of Applied Mechanics in the University of Toronto.

TESTS OF CONCRETE COLUMNS MADE UNDER BUILDING CONDITIONS

by H. C. Berry

In Engineering News, Vol. 61, page 206, 1910

Tests were made on 9 full size plain and reinforced concrete columns made under the actual conditions of building construction. The columns were 14 in. square and 12 ft. long. Three of the columns were of plain concrete, three had longitudinal reinforcement (1.15%) and three had spiral in addition to the longitudinal reinforcement (1.75% spiral and 2.4% longitudinal). The spiral consisted of a 5/16-in. round wire wound on 12 in. diameter at a 1-1/2 in. pitch. The concrete was of 1:2:4 mix having 3/4 in. maximum size of aggregate. The yield-point stress of the longitudinal reinforcement was 44,000 lb. per sq.in. and the ultimate strength 61,000 lb. per sq.in. Three 8 by 16-in. cylinders and three 6-in. cubes served as control specimens. The average strength of the cubes was 2,880 lb. per sq.in., and of the cylinders 2,420 lb. per sq.in. The average strength of the plain columns was 2,500 lb. per sq.in. The average strength of the columns having 1.15% longitudinal but no spiral reinforcement was 2,580 lb. per sq.in. and the strength of the columns with 2.4% longitudinal and 1.75% spiral reinforcement was 2,810 lb. per sq.in. The uniformity in test

results was very good, the maximum variation from the average being less than 10%. The modulus of elasticity for stress less than 500 lb. per sq.in. was less for the plain columns than for the reinforced columns. The difference, however, was not large.

The maximum loads on the reinforced columns agreed within 10% with values obtained by the formula:

$$P = A.f_c(1 + (n-1).p)$$

if 2,500 is used as the value for f_c , and 10 for n . The strength results were based on full area of the column, for it was evident that the concrete outside the spiral helped to support the load until the maximum was reached.

TESTS OF REINFORCED CONCRETE COLUMNS

SERIES OF 1910

by M. O. Withey

Bulletin of the University of Wisconsin, No. 466 (1911)

This bulletin contains the report of a continuation of the column investigation reported in Bulletin 300. Sixty-six columns were made and the results reported. The purpose of the tests was to study: (1) the effect of varying the percentage of spiral reinforcement, (2) the effect of varying the percentage of longitudinal reinforcement, (3) the effect of varying the richness of the mixture, (4) the effect of a small number of repeated loadings, (5) the effect of maintaining a constant load for different time intervals, (6) the behavior of columns eccentrically loaded, (7) the relative value of plain and deformed bars for longitudinal reinforcement, and (8) the effects of differences in end conditions.

The spiral reinforcement was cut to the column length and the ends of the wire were turned inward so as to provide anchorage against slipping. The longitudinal rods were milled to approximately the same length and were tied to the inside of the spiral at regular intervals. The columns were capped with a 1-1 mortar, the capping plate being forced down upon

the ends of the longitudinal bars as far as possible. The columns remained in the molds for four to six days. After the removal of the forms the columns were wetted twice a day for at least one week and thereafter once a week until tested.

Both longitudinal and lateral deformations were observed.

The results of the tests showed that closely spaced spiral reinforcement increased the toughness greatly, and the ultimate strength considerably, but did not materially raise the yield point. Longitudinal reinforcement used in spirally reinforced columns increased the yield-point and ultimate strength of the columns.

Columns of different concrete mixes showed that the richer mixes were the more economical for a given strength and that an increase in richness of the mix was more economical for adding strength to the column than an increase in percentage of longitudinal reinforcement.

The tests on columns loaded eccentrically showed that a fair agreement existed between test results and values computed by the general formula:

$$S = \frac{P}{A} + \frac{M \cdot e}{I}$$

Columns with longitudinal bars spread into a footing showed about the same strength as similar columns tested upon metal bases provided the footing was made sufficiently thick.

The general equation for the yield-point stress of reinforced concrete columns was given as:

$$\frac{P_1}{A} = (1-p)f_c + pf_s$$

and for ultimate strength:

$$\frac{P}{A} = (1-p)f_c + pf_s + K.p'.f_s'$$

where P = maximum load

P_1 = yield-point load

A = area inside of spiral

p = percentage of longitudinal steel

p' = percentage of lateral steel

f_c = ultimate strength of concrete

f_s = yield-point stress of longitudinal steel

f_s' = yield-point stress of lateral steel

K = a constant

REPORT OF COMMITTEE
ON REINFORCED CONCRETE AND BUILDING LAWS
TESTS OF REINFORCED CONCRETE COLUMNS

In Proceedings, American Concrete Institute, 1915, page 407

Twenty-four columns were tested. The spiral reinforcement was either 0, 1, or 2%, and the longitudinal reinforcement varied from 0 to 6%. Both longitudinal and lateral deformation measurements were taken. The columns had generally a diameter of 21 in., the spiral diameter being 20 in., and the shaft length was 9 ft. 4 in. Two columns were designed to show the effect of the protective shall and had a diameter of 24 in. The concrete was a 1:1-1/2:3 mix. Two 8 by 16-in. cylinders were made with each column. Age at test was 115 days.

Columns with longitudinal reinforcement, but no spiral, gave strength results approximately according to the formula:

$$f = 3000 (1-p) + 40,000p$$

The cylinder strength of the concrete had an average of approximately 3000 lb. per sq.in. The spirally reinforced columns showed that the spiral was very slightly stressed for loads below the maximum found for columns with no spiral reinforcement. Beyond this load the spiral was stretched

more rapidly and at the maximum load on the column the spiral was nearly stretched to its ultimate strength. Hardly any spalling off was found for the columns at maximum load. The equation given for strength of spirally reinforced columns was:

$$f = 3000 (1-p) + 40,000p + 160,000 (1-10p) q$$

where p is percentage of longitudinal and q percentage of spiral reinforcement.

The two columns having fireproofing shell gave the same maximum strength as the columns without shell. The shell did not crack or spall off before the maximum load had been reached. At maximum load the shell rapidly cracked and part of the shell fell off.

The following conclusions were reached from these tests:

"1. They seem to confirm the current practice as to the effect of varying percentages of longitudinal reinforcement within the range of these tests as expressed in the following formula: $f = f_c(1-p) + n.f_c.p$

2. They indicate that columns with spiral reinforcement are stronger and tougher than columns with no spiral reinforcement.

3. For these tests it would appear that the spiral reinforcement is approximately four times as effective in giving ultimate strength to the column as the same volume of longitudinal reinforcement.

4. It appears that the effect of the longitudinal reinforcement decreases as the percentage of spiral reinforcement increases."

REPORT ON A SERIES OF TESTS ON CONCRETE COLUMNS
REINFORCED WITH A SPIRAL OF STEEL

C. G. Wrentmore, Hugh Brodie, and C. O. Carey
In Transactions, American Society of Civil Engineers
1915, Vol. 78, page 97

A total of 104 columns were tested in this investigation. All columns were approximately 4 in. in diameter and 27 in. long. The concrete mix was 1:2:4 by loose volume and was mixed by hand. The mix was rather wet but did not segregate. The columns were cured in water and tested in a cushion of sand. Great care was taken in observing longitudinal and lateral deformations. The percentage of spiral reinforcement varied from 0 to 4.10%. All groups of columns showed an increase in strength with age at test. Plain concrete columns with spiral wound on the outside under tension before the test, showed higher strength than did columns originally reinforced with the same amount of spiral. The deformation of plain columns was found to be less for the same stress than for the spirally reinforced columns.

The following conclusions were drawn from the investigation:

- "1. The value of Poisson's ratio is approximately 8 for short-time, and 7 for long-time tests.
2. The value of μ is in general below 10, only exceeding that value for short-time and high stress.

3. Spiral reinforcement does not, by its restraining effect on the core, perceptibly affect the value of μ (Poisson's ratio) or n (moduli ratio) for stresses below 900 lb. per sq.in.

4. Spiral reinforcement does not perceptibly assist the concrete in carrying the load within the limits of ordinary working stresses.

5. The limit at which the first visible sign of failure occurs is raised by spiral reinforcement. This effect is greatest in short time tests and is perceptible for all percentages of reinforcement.

6. The plain column fails abruptly, giving no warning of approaching collapse. The hopped column may be depended on to give warning at approaching failure at from 70 to 90% of the ultimate strength, when not less than 0.50% steel is used.

7. The deformation is quite irregular up to about 400 lb. per sq.in.; above this it is quite regular up to a limit which is not defined by these tests, but is well above allowable working stresses.

The tests indicate, but cannot be said to prove conclusively, that:

8. The ultimate strength of the column is increased by spiral reinforcement by an amount roughly proportional to the quantity of steel used, up to the limit of 1.58%; and above this limit the ultimate strength is simply the amount which can be carried by the granular core supported by the spiral, but with no cohesion of its own."

TESTS ON CONCRETE COLUMNS, PLAIN AND REINFORCED

by Frank P. McKibben and A. S. Merrill

In Proceedings, American Concrete Institute

1916, Vol. 12, page 200

The number of columns tested was 33. The columns were about 14 in. in diameter and from 5 to 20 ft. long. The concrete mix was 1:2:4. Nine columns were of plain concrete and 24 reinforced. The spiral reinforcement varied from 0.46 to 3.82%, and the longitudinal reinforcement from 0 to 4%. The purpose of the tests was to study on the following subjects; lateral and longitudinal deformations, effect of increasing the percentage of spiral steel, effect of length on plain, as well as on spirally reinforced columns, the value of longitudinal as compared with spiral reinforcement.

The maximum size of coarse aggregate was about 1-1/2 in. The average weight of water was 8% of the combined weights of cement, sand, and stone. One 8 by 16-in. control cylinder was made and tested simultaneously with each column. The columns had no fireproofing shell. The yield-point stress of the spiral wire was about 67,000 lb. per sq.in., and of the vertical steel 33,000 in tension and 35,000 lb. per sq.in. in compression.

The age at test varied from 73 to 82 days. The columns were sprinkled twice daily from the time of removal from form until time of test. The control cylinders were stored in moist sand throughout the curing period. The average ultimate strength of the control cylinders from the plain columns was 2174 lb. per sq.in. The average ultimate strength of the plain columns was 2090 lb. per sq.in. for 5-ft. columns, 1767 for 10-ft. columns, and 1748 lb. per sq.in. for 20-ft. columns.

A considerable variation was found in the modulus of elasticity as well as in Poisson's ratio for individual plain columns. During the application of the loads, the first visible effect of compression was the buckling of the outer straps of the spacers for the spirals, which began at unit compressive stresses slightly above the ultimate strength of plain concrete. At higher stresses this was followed by spalling of the concrete. Except for the 20-ft. columns which buckled nearly 2 in., failure in almost all cases was accompanied by breaking of spirals shortly after the maximum load had been reached. The spiral reinforcement increased the ultimate strength practically in proportion to the percentage of the spiral up to a percentage of 1%. For percentages larger than one, the rate of increase was not so great. For the 10-ft. columns 0.46% spiral increased the strength by 89%, 0.96% increased the strength 169%, and 1.95% increased the strength 205% over the strength of the plain columns. For

stresses less than about 2500 lb. per sq.in., the longitudinal deformations were only slightly affected by the spiral reinforcement, but under large compressive stresses the spiral restrained the lateral swelling of the concrete so that the longitudinal deformations were retarded. The longitudinal steel affected the longitudinal deformations very little at low loads. The ultimate strength of the columns increased quite regularly with the increase in longitudinal reinforcement.

THE FAILURE OF PLAIN AND SPIRALLY REINFORCED CONCRETE
IN COMPRESSION

by F. E. Richart, Anton Brandtzaeg, and R. L. Brown
University of Illinois, Bulletin No. 190, 1929

The tests included 23 columns 10 in. in diameter and 40 in. long. The percentage of spiral reinforcement varied from 0 to 4.41% and three kinds of wires were used, annealed drawn, rolled mild, and suspension cable wire. For the plain columns five similar specimens were made, while three of a kind were used for the other groups. The concrete mix was 1:2.1:2.5 by loose volume for all specimens. The net water-cement ratio was 0.87 by loose volume and the average slump was 6.9 in.

Tests of the spiral wires showed that the stress-strain curves for the wires were changed by the coiling so that no sharp yield point was evident.

The columns and their control cylinders were capped with neat cement paste soon after the making. The specimens were removed from the molds when two days old, and stored under wet burlap for 24 days. The burlap was then removed and the specimens allowed to dry for two days and then tested.

During the testing it was noted that if a spirally reinforced column had been loaded to its maximum load, and

loading was stopped for a short time and then resumed, a second maximum load was obtained. This second maximum load was usually slightly higher than the first.

The following table gives the average strength for columns having different amounts of spiral reinforcement.

| Strength of Control Cylinders lb.per sq.in. | Percent Spiral Reinforcement | Strength of Column lb. per sq. in. | Kind of Spiral Wire | Yield-point Strength of Wire lb.per sq.in. |
|---|------------------------------|------------------------------------|---------------------|--|
| 2425 | 0 | 2130 | - | 67,000 |
| 2700 | 0.50 | 2680 | Annealed Drawn | 67,000 |
| 2725 | 1.11 | 3590 | Annealed Drawn | 61,000 |
| 2730 | 2.07 | 3665 | Rolled Mild | 38,000 |
| 2615 | 2.64 | 4295 | Rolled Mild | 40,000 |
| 2775 | 4.41 | 6430 | Rolled Mild | 46,000 |
| 2685 | 1.96 | 7880 | Suspension Cable | 106,000 |

Deformation observations on plain columns showed that the ratio between lateral and longitudinal deformations increased with the stress, and at ultimate strength generally was equal to one-half. The flow of concrete at high stresses was found to be considerably larger for the lateral deformation than for the longitudinal deformation. The volume of the

columns decreased with the load up to a stress of approximately 80% of the ultimate. Beyond this stress the volume increased and at ultimate load the apparent volume was larger than the volume at the beginning of the test. In the reinforced columns having spirals of annealed drawn wire, the spiral fractured with further loading after the maximum load had been reached. None of the rolled mild steel spirals were broken in the tests, but each of the high carbon spirals broke at gage holes in the steel and caused failure at a time when the column was still taking load rapidly.

- It was found that the spirals depressed into the concrete as the load increased and that the relation between depression and spiral stress was nearly a linear one. It is stated that the relative movement between spiral and concrete probable was very largely a plastic flow of the concrete between the spiral wires.

The effect of the spiral reinforcement on the strength of the column was found to follow the formula:

$$f_c = f_c' + 4.1f_s$$

where f_c = strength of column

f_c' = compressive strength of plain concrete

and f_s = lateral stress.

In terms of the spiral stress f_s , and the percentage of spiral p , the equation becomes:

$$f_c = f_c' + 2.05 pf_s$$